

**Final Summary of Research Report
to the
National Aeronautics and Space Administration**

Cosmochemistry Program

NASA Grant NAG5-11912

For the period 4/15/2002 to 4/14/2003

**Principal Investigator: Conel M. O'D. Alexander
Department of Terrestrial Magnetism
Carnegie institution of Washington
5241 Broad Branch Road, N.W.
Washington, DC 20015**

Introduction

The discovery of presolar grains in meteorites is one of the most exciting recent developments in meteoritics. Six types of presolar grain have been discovered: diamond, SiC, graphite, Si₃N₄, Al₂O₃ and MgAl₂O₄. These grains have been identified as presolar because their isotopic compositions are very different from those of Solar System materials. Comparison of their isotopic compositions with astronomical observations and theoretical models indicates most of the grains formed in the envelopes of highly evolved stars. They are, therefore, a new source of information with which to test astrophysical models of the evolution of these stars. In fact, because several elements can often be measured in the same grain, including elements that are not measurable spectroscopically in stars, the grain data provide some very stringent constraints for these models.

Our primary goal is to create large, unbiased, multi-isotope databases of single presolar SiC, Si₃N₄, oxide and graphite grains in meteorites, as well as any new presolar grain types that are identified in the future. These will be used to: (i) test stellar and nucleosynthetic models, (ii) constrain the galactic chemical evolution (GCE) paths of the isotopes of Si, Ti, O and Mg, (iii) establish how many stellar sources contributed to the Solar System, (iv) constrain relative dust production rates of various stellar types and (v) assess how representative of galactic dust production the record in meteorites is. The primary tool for this project is a highly automated grain analysis system on the Carnegie 6f ion probe.

Silicates are the most abundant form of dust in stellar winds and in the interstellar medium. The recent discovery that presolar silicates are highly abundant in IDPs confirms that such minerals were present in the early Solar System and might also be preserved in meteorites. Circumstellar silicates of crystalline enstatite and forsterite have been observed around O-rich asymptotic giant branch (AGB) stars. Since we have micron-sized oxide minerals from such stars, these refractory silicate grains should also survive in meteorites, exhibit large isotopic anomalies in Si and O and be detectable with our ion probe. However, most silicates in meteorite matrices are certainly of solar system origin. Additionally, ⁵⁴Cr enrichments in certain leach fractions of several chondrites are believed to point to a new type of presolar grain, soluble in the usual acid treatments used to isolate presolar grains. Clearly new techniques are needed to isolate and identify such phases in meteorites.

Progress

New sample preparation techniques and the search for presolar silicates and the ⁵⁴Cr carrier.

We have conducted an initial ion probe search for presolar silicates (Alexander et al., 2001) in a Murchison residue rich in micron-sized enstatites and oxides, prepared with the new technique. We analyzed $^{18}\text{O}/^{16}\text{O}$ ratios in ~1500 grains from the residue. None of the 1175 analyzed enstatite grains were found to be presolar, but one presolar Al-rich oxide grain was found.

We have also made significant recent progress towards isolating the anomalous ^{54}Cr carrier in primitive meteorites. Leaching experiments by Alexander et al. (2001) and Alexander (2002) indicated that the ^{54}Cr carrier is concentrated in the organics-rich CsF residues of Orgueil, Murchison and Tagish Lake. Moreover, the Cr isotope composition was surprisingly similar ($\delta^{54}\text{Cr} \sim 20\text{‰}$) for leachates from these three meteorites. We believe it is likely that the carrier is not the organic material itself, but rather a Cr-rich mineral grain entrapped in the organics. Thus, we have conducted an initial ion probe survey of micron-sized grains in the ^{54}Cr -rich residue of Orgueil, from which the organics were removed by plasma ashing (Nittler and Alexander, 2003b). Automated O-isotope mapping of ~260 grains identified three ^{17}O -rich oxide grains, including two members of a new presolar phase, a solid solution of spinel and magnesiochromite (MgCr_2O_4). This is the first discovery of a Cr-rich presolar grain and brings the number of known O-rich presolar grain types to seven. It is unlikely that this phase is sufficiently soluble in HCl to be the *dominant* carrier of ^{54}Cr excesses in the meteorite, but it is a strong candidate for being *a* carrier. Clearly, much more work is needed, but the presolar magnesiochromite-spinel discovery suggests we are on the right track.

The new dissolution technique has proven to be useful for isolating refractory presolar grains as well. For example, using this technique it is possible to prepare SiC and refractory oxide residues much more rapidly than with standard techniques (in a matter of days, compared to weeks to months for a typical acid residue). Moreover, presolar Si_3N_4 appears to survive the CsF treatment better than the old methods.

Isotopic compositions of presolar Al_2O_3 and MgAl_2O_4 grains

In the past year, we have made further progress in our presolar grain studies. In addition to the discovery of presolar magnesiochromite (see above), we have used the Mainz NanoSIMS (with collaborator Hoppe) to measure Ti and Mg isotopic ratios in several presolar grains. Ti was measured in three presolar Al_2O_3 grains from our Tieschitz and ordinary chondrite mounts and one Al_2O_3 grain identified in Mainz (Hoppe et al., 2003). The data are broadly consistent with expectations for Galactic Chemical Evolution (GCE) of Ti and nucleosynthesis in the low-mass red giants and AGB stars believed to be the parents of these grains. However, they also provide new constraints. For example, the observed Ti patterns for three of the measured grains are best described by AGB star models in which a smaller than standard amount of ^{13}C is mixed below

the H shell of the star in order to produce neutrons. Since the amount of mixed ^{13}C is a free parameter in these AGB models, the grain data clearly provide valuable new information.

Mg isotopes were measured in seven presolar spinel grains from our OC mounts (Nittler et al., 2003). Our primary goal was to search for $^{25}\text{Mg}/^{24}\text{Mg}$ variations either from GCE or nucleosynthesis. Previous studies had found little variation in this isotope ratio in SiC or Al_2O_3 , but low Mg contents in the studied grains made contamination a concern and limited the precision. Targeting spinel for Mg measurements greatly reduces both problems. Most of the measured grains have close-to-Solar Mg ratios, but one grain, OC2, showed very large excesses of both ^{25}Mg and ^{26}Mg . This grain also showed a "Group 2" O-isotope pattern, highly depleted in ^{18}O and enriched in ^{17}O . The O and Mg isotopic data of OC2 are best explained if it formed in a $4\text{--}5M_{\odot}$ O-rich AGB star undergoing "hot bottom burning," wherein H-burning reactions occur at the base of the stellar envelope. This is the first strong evidence from presolar grains that hot bottom burning occurs and that intermediate mass AGB stars contributed dust to the presolar grain inventory. Moreover, most previous studies have favored a low-mass star origin for the ^{18}O -depleted oxide grains. The OC2 result indicates that Mg data can help determine the mass of the parent stars. The Mg data for the other grains are suggestive that the $^{25}\text{Mg}/^{24}\text{Mg}$ ratio of the Galaxy evolves much more slowly than predicted by numerical models of Galactic chemical evolution. This result is consistent with previous data for presolar SiC, presolar Al_2O_3 and main sequence stars, and might have important implications for nucleosynthesis in the early stages of our Galaxy.

Presolar SiC and Si_3N_4 Grains

We have now used our automated analysis system to acquire Si- and C-isotopic data for ~3,300 1-5 μm SiC grains isolated from the Murchison meteorite, with ~90% of these grains being isolated using the new CsF technique. This is more than twice the total number of individual grains for which both Si and C data have previously been obtained. Isotopic ratios of both of these elements are needed to unambiguously identify all known SiC sub-groups and we identified a large number of X, Y, Z and A+B grains (Figure 1). In addition, we identified a few grains of probable nova origin, three presolar Si_3N_4 grains, and a highly unusual grain with a 2- ^{30}Si enrichment, modest ^{29}Si enrichment and isotopically light C. These data are discussed in detail in (Nittler and Alexander, 2003a), but the key points of that discussion can be summarized here: i) the new data are broadly similar to previous observations in terms of ranges of isotopic ratios and compositions and abundances of sub-groups; ii) Minor differences in isotopic distributions between our data and prior data can be partially explained by terrestrial contamination and grain aggregation on sample mounts. However, some of the differences are probably intrinsic to the samples, possibly due to the different chemical techniques used to prepare samples. iii) The abundance of presolar Si_3N_4 in our sample is ~3 times higher than that

previously observed in Murchison, indicating that this mineral survives the new acid treatments better than the standard ones. iv) There is a striking correlation between the inferred initial metallicity and inferred amount of He-shell material dredged-up in the parent AGB stars of the Z-type SiC grains. This trend smoothly connects the Z, Y and mainstream grains, consistent with the belief that these types formed in AGB stars with a range of metallicities. v) The isotopic data for Z grains indicates that many of their parent stars must have undergone strong CNO-cycle H-burning during the early AGB phase, consistent with either cool-bottom processing in low-mass stellar parents or hot-bottom burning in intermediate mass parents. vi) The trend of $^{12}\text{C}/^{13}\text{C}$ ratios as a function of $^{29}\text{Si}/^{28}\text{Si}$ ratios for SiC grains indicates a sharp increase in the maximum mass of the parent stars with decreasing metallicity, in contrast to expectations from GCE theory.

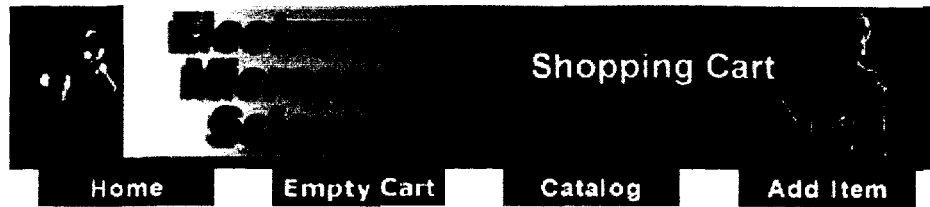
Galactic Chemical Evolution of isotopic ratios

The Si and Ti isotopic compositions of mainstream SiC are most often interpreted in terms of the theory of Galactic chemical evolution (GCE). We have previously used the SiC Si and Ti isotope data to estimate the GCE paths of their minor isotopes as a function of metallicity (Alexander and Nittler, 1999). In this model, we assumed that the interstellar medium (ISM) is well mixed and that therefore there is a unique isotopic and elemental composition associated with stars of a given metallicity. However, this is known to be an oversimplification, since mixing of stellar ejecta into the ISM cannot be instantaneous and observations indicate a large range in metallicity for stars of a given age and location in the galaxy. To address this issue, Lugaro et al. (1999) performed Monte Carlo mixing models to estimate the range of isotopic variation expected in presolar grains, due to inhomogeneous galactic chemical evolution. They found that the entire range of Si isotopic ratios observed in mainstream SiC can be explained by this model. This model has the attractive feature that the isotopic heaviness of the grains is easily explained, but if correct, it precludes the possibility of inferring metallicities for the parent stars of individual SiC grains. Lugaro et al. (2001) extended the model to Ti isotopes but found it did not reproduce the grain data as well as for Si. Last year, we extended the Monte Carlo model of Lugaro et al. (1999) to explore whether it can account for the combined data of Si and Ti in mainstream SiC and O and Ti in presolar oxides (Nittler, 2002). We reproduced the results of Lugaro et al. (1999) for Si isotopes but found that the model greatly under predicts the range of $^{18}\text{O}/^{16}\text{O}$ ratios observed in presolar oxide grains. Moreover, we found that the good agreement between the Monte Carlo model and the grains for Si is a fortuitous result of the fact that the yields of $^{29,30}\text{Si}$ in Type II supernovae of different masses are strongly correlated. The model utterly fails to reproduce the high degree of correlation observed between Si and Ti isotopic ratios in the grains, since the relevant supernova yields are uncorrelated. We believe this argues strongly against the isotopic variations in presolar grains being dominated by inhomogeneous GCE. A paper

discussing this Monte Carlo model and its implications is close to completion and will be submitted to the *Astrophysical Journal* shortly.

References

- Alexander C. M. O. D. and Nittler L. R. (1999) The Galactic chemical evolution of Si, Ti and O isotopes. *Astrophys. Journ.* **519**, 222-235.
- Alexander C. M. O. D., Nittler L. R., and Tera F. (2001) The search for presolar silicates and the ^{54}Cr carrier. *Lunar Planet. Sci.* **XXXII**, CD#2191.
- Alexander C. M. O. D. (2002) The carrier of the ^{54}Cr anomaly: Ubiquitous and iniform in composition. *Lunar Planet. Sci.* **XXXIII**, #1872 (abstr.).
- Hoppe P., Nittler L. R., Alexander C. M. O. D., and Marhas K. K. (2003) A NanoSIMS study of titanium-isotopic compositions of presolar corundum grains. *Lunar Planet. Sci.* **XXXIV**, #1570 (abstr.).
- Nittler L. R. (2002) Meteoritic stardust and the clumpiness of galactic chemical evolution. *Lunar Planet. Sci.* **XXXIII**, #1650 (abstr.).
- Nittler L. R. and Alexander C. M. O. D. (2003a) Automated isotopic measurements of micron-sized dust: Applications to meteoritic presolar silicon carbide. *Geochim. Cosmochim. Acta* **67**, 4961-4980.
- Nittler L. R. and Alexander C. M. O. D. (2003b) Chromium-bearing presolar oxide grains in a ^{54}Cr -rich orgeuil residue. *Meteoritics Planet. Sci.* **38**, A129.
- Nittler L. R., Hoppe P., Alexander C. M. O. D., Busso M., Gallino R., Marhas K. K., and Nollet K. (2003) Magnesium isotopes in presolar spinel. *Lunar Planet. Sci.* **XXXIV**, #1703 (abstr.).



View Shopping Cart

⇒ CHECKOUT					
Catalog	Item	Quantity	Unit	Price	Total
50400-05	CRYSTALBOND 509, 5 STICKS/PK	1	PACK	\$124.00	\$124.00
		UPDATE	Total		\$124.00

Electron Microscopy Sciences

Request a Catalog | Homepage | Email: sgkcck@aol.com

*In PA (215) 412-8400 * Toll-Free (800) 523-5874 * Fax (215) 412-8450*